# What Are the Interactions among Ice Masses, Oceans, and the Solid Earth, and the Implications for Sea-Level Change?

Coastal erosion, such as that shown above in Pacifica, California, is a pervasive problem that threatens many homeowners.

***Expected Accomplishments***

- *Accurate estimation and prediction of global hydrological mass fluxes, including those of ice sheets and glaciers.*
- *Separation and prediction of steric (thermal and salinity) and mass-budget contributions in sea-level change.*
- *Separation of solid-Earth vertical motion (tectonic, post-glacial rebound, and environmental) from true sea-level change.*

***Benefits for the Nation***

- *Improved estimates of future sea-level rise*
- *Improved assessment of coastal erosion due to sea-level rise*
- *Long-term planning for coastal communities affected by sea-level rise*

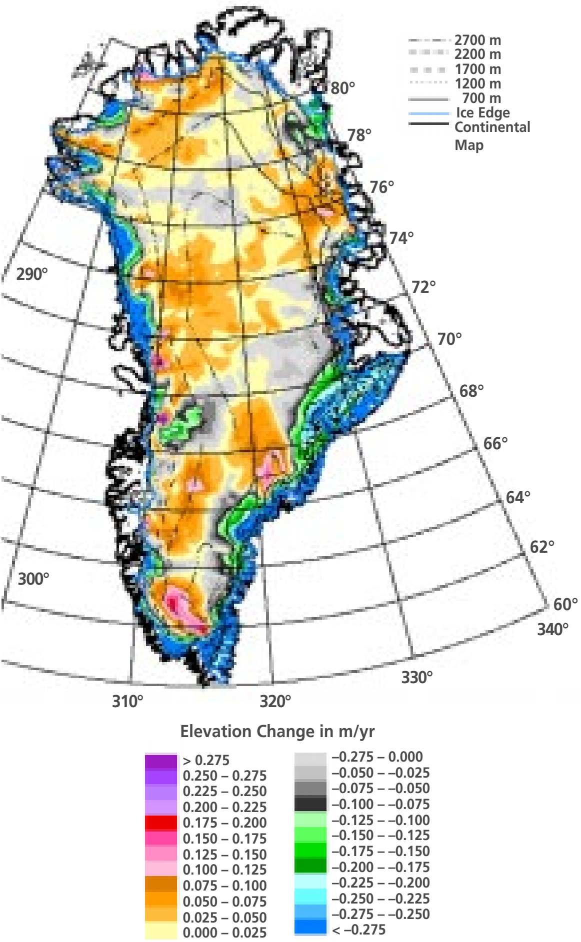
"Glaciers are delicate and individual things, like humans. Instability is built into them."

*Will Harrison, glaciologist,1986*

### The Challenge

Today more than 100 million people worldwide live on coastlines within one meter of mean sea level. Any short-term or long-term sea-level change relative to vertical ground motion is of great societal and economic concern. The very survival of many island states and deltaic coasts is threatened by sea-level rise. Inasmuch as paleo-environmental and historical data have clearly indicated the occurrence of such changes in the past, new scientific information on the nature and causes of sea-level change — and the development of a quantitative predictive capability — are of utmost importance for the future. This topic is inherently an interdisciplinary science problem addressed within NASA by the Cryospheric Science, Ocean Science, Hydrology, and Solid Earth Science Programs.

The 10–20 cm global sea-level rise recorded over the last century has been broadly attributed to two effects: the steric effect (thermal expansion and salinity-density compensation of sea water) of changes in global climate, and mass-budget changes due to a number of competing geophysical and hydrological processes in the solid Earth–atmosphere–hydrosphere–cryosphere system. While the steric effect is primarily a climatic issue, the Solid Earth Science Program is poised for a fundamental contribution by separating the two effects via a combined use of space geodetic measurements of sea-surface topography and time-variable gravity. The mass-budget changes include water exchange from polar ice sheets and mountain glaciers to the ocean, atmospheric water vapor and land hydrological variations, and human effects such as water impoundment in artificial reservoirs and extraction of groundwater. These exchanges are




*Elevation changes in Greenland have been measured by airborne laser altimetry. The ice sheet appears to be in balance with snow accumulation at high elevation, but thinning predominates at low elevation. Overall, the Greenland Ice Sheet is estimated to lose mass to the ocean. Dramatic thinning occurs in largely understudied southeastern Greenland.*

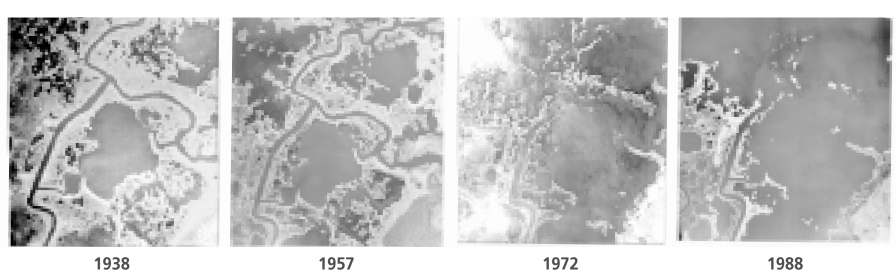
all superimposed on the vertical motions of the solid Earth due to tectonics, rebound of the lithosphere from past and present deglaciation, and other local ground motions. A number of space geodetic measurements of sea-surface topography, ice mass, gravity, and ground motions are directly relevant. A complete knowledge of sea-level change will then emerge and be used for the development of predictive global and regional models.

### What We Know and Need to Learn about the Mass Balance of Earth's Ice Cover and Sea-Level Change

Globally sea level is estimated to rise by 1.5–2 mm/year, but few details are known. The relative contributions of the steric and mass-budget effects are under debate, as are their spatial and temporal variations. We are presently not certain whether Greenland and Antarctica are gaining or losing net ice mass. Estimates of mountain glacier melting are incomplete. The global land hydrological budget is not well known. Even the amount of artificial reservoir water impoundment is uncertain by perhaps a factor of two. If global warming continues, a most immediate and potentially dominant mass-budget contribution to sea-level change is likely to come from the melting of ice masses. The melting of temperate glaciers could raise sea level by a few tens of centimeters; the melting of the ice sheets in West Antarctica could raise sea level by several meters. Global and temporally continuous monitoring of sea-surface topography, ice mass, gravity, and ground motions is needed. Knowing how the present ocean "container" deforms is also necessary to predict the consequences of sea-level change. On a global scale, that requirement calls for an accurate post-glacial rebound model incorporating knowledge of the Earth's internal mechanical properties and the history of past ice ages. At any given location along the coastline, additional tectonic motion and environmental impacts such as groundwater withdrawal need to be monitored and understood.

### Next Steps

Measuring absolute as well as relative sea-level change is a geodetic endeavor. Further advances in geodetic measurement techniques must provide information on sea-level changes and consequences in a routine fashion, with enhanced geographical coverage, spatial and temporal resolution, and measurement accuracy. Research is needed to integrate the various relevant measurements — changes in sea- and ice-surface topography, time-variable gravity, deformation of the surface of the solid Earth (particularly along coastlines), all under a uniform terrestrial reference frame, together with in situ measurements from tide gauges and buoys, remote-sensing data such as sea-surface temperature and salinity, and global atmosphere–hydrosphere–cryosphere models that assimilate diverse climatic data types.




*Aerial photo sequence spanning 50 years showing the progressive drowning and loss of coastal marshes in Blackwater National Wildlife Refuge near Cambridge, Maryland, in response to a rise in sea level relative to local land. The area shown is about 1 km across.*